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THE DEVELOPMENT OF CRITERIA FOR RADIOACTIVE WASTE DISPOSAL

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PAPER

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1. INTRODUCTION

It is widely recognized that one of the most difficult aspects of radioactive waste management that nuclear regulatory authorities are faced with is the establishment of reasonable and acceptable criteria for radiation protection in the long term. Such criteria are necessary for judging the acceptability of waste disposal options, and their supporting documentation, whenever there may be potential radiological implications beyond the time for which it is reasonable to use institutional controls for ensuring an acceptable level of safety.

While long-term radiation protection criteria and the factors directly associated with them are of paramount interest at this workshop, it must also be recognized that there are other quantifiable and non-quantifiable factors of a non-radiological nature that will have to be taken into account in making decisions on waste disposal. These factors may have to do with other technical issues, such as environmental protection, use of resources, methods of financing, conventional safety and other social and political factors, including acceptability and siting considerations. Some of these factors also require the development of criteria that satisfactorily address the long term. However, they are simply mentioned here since there is evidence from past and present experience to suggest that they may combine to play the major role in decision-making. In this circumstance, the difficulties in dealing with long-term radiation protection criteria may pale in significance. Nonetheless, the importance of establishing technically defensible radiation protection criteria cannot be overemphasized in view of the plans and programs presently underway in Canada to dispose of long-lived radioactive wastes.

2. APPLICABILITY OF ICRP SYSTEM OF DOSE LIMITATION

When considering radiation protection criteria for the long-term aspects of waste disposal, there is a natural tendency to consider the application of the ICRP system of dose limitation[1] as the obvious basis for a regulatory framework.

The three principles of justification, optimization and individual dose limitation are generally intended to apply to all practices in which radiation exposure of workers and the public can be influenced by active controls, excluding non-routine exposures, medical irradiations and exposures to natural background radiation. However, the justification principle is meant to apply to the overall practice producing a positive net benefit. In this case, waste disposal is but one activity of many in the nuclear fuel cycle which has already been justified, rather than an isolated practice that remains to be justified. The principles of optimization and individual dose limitation, on the other hand, can be, and are, applied directly to the operational aspects of waste management and disposal where liquid and gaseous effluents are routinely discharged from nuclear facilities. In this situation, radionuclides are dispersed into receiving water bodies or the atmosphere at controlled rates, and exposures and costs are reasonably well known.

THE DEVELOPMENT OF CRITERIA FOR RADIOACTIVE WASTE DISPOSAL

ABSTRACT

Radiation protection criteria are needed in Canada for judging the acceptability of radioactive waste disposal options for which there are potential long-term radiological impacts. This paper discusses the difficulties encountered in applying the ICRP system of dose limitation to the long term and the alternative approaches to criteria being developed and adopted by various other international and national bodies. Finally, the present situation in Canada is reviewed and conclusions are drawn on the general direction in which national criteria are being formulated and expressed.

RÉSUMÉ

Le Canada a besoin de critères de radioprotection pour juger du bien-fondé des différentes méthodes d'évacuation des déchets radioactifs qui pourraient avoir des répercussions radiologiques à long terme. Le présent rapport traite des difficultés d'application à long terme du système de limitation de doses de la CIPR et des autres approches que différents organismes nationaux ou internationaux sont en train de mettre au point ou ont déjà adoptées. Il aborde enfin la situation actuelle au Canada et tire des conclusions sur la direction générale vers laquelle les critères nationaux sont formulés et exprimés.

It is for the post-operational phase of the disposal of solid wastes by long-term containment and isolation that difficulties arise in applying the principles of optimization and individual dose limitation. In this situation, the release of radionuclides into the environment is dependent on events and processes which may be more or less certain to occur and may have time-varying probabilities of occurrence. As a consequence, the dose limit can only be applied for a defined set of conditions in which the likelihood that an individual will receive a dose in a predicted range can be assumed to approximate unity. Other lower probability scenarios can then be envisaged which if they were to occur would lead to doses above the limit. Similarly, in optimization considerations, measures might be taken in the design and implementation stages to reduce the doses from one set of future conditions while other sets of conditions, which might entail greater doses might be neglected.

An additional dilemma arises when the general situation is considered in which the system of dose limitation is intended to apply. Thus, the system requires the implementation of a program of active regulatory compliance and enforcement. For the disposal of long-lived waste, such a program is not possible over the timescales for which radionuclide releases and exposures are likely to occur. Beyond the time for which institutional controls are maintained, there can then be, in the strict sense, no active limitation of exposures in the manner practised today.

There are other issues encountered when trying to apply the present system of dose limitation as recommended by the ICRP. In applying the dose limits to individual members of the public, these issues concern the use of the critical group concept, the treatment of multiple sources, the dose to be calculated and the time period for such calculations. The issues arise in view of the obvious uncertainties concerning the location, habits and types of individuals likely to receive the highest doses, the number and variety of sources of exposure that might be involved, the physico-chemical form of the radionuclides in the environment and the importance to be assigned to doses in the future.

Although not an issue peculiar to the disposal of long-lived waste, inasmuch as there is a similar concern today, there is also a need to consider individual exposures that might be of short or extended duration. Thus, for waste disposal practices with long-term implications, there are situations in which the doses received involve exposures over the life-times of the individuals, for example, habitation or farming near, or on, a shallow land burial facility. On the other hand, there are situations where there may be short duration but high exposures of individuals, for example, excavation and construction of buildings or roads on the same shallow land burial facility.

In applying the optimization principle by conducting a differential cost-benefit analysis of alternative options, the inherent difficulties in assigning a monetary value to unit collective dose and in the need for realistic and reliable assessments of collective dose commitment are compounded in waste disposal by the following:

- the ICRP recommended that all individual doses be taken into account no matter what level below the individual limit, when they occur or where they occur, except when either:

  - a common collective dose component can be excluded because it does not contribute to distinguishing between alternatives;

  or;

  - a small, identified component of the collective dose can be excluded because it does not add significantly to the total value;

- the desire, for practical reasons, to use generic cut-offs for individual dose, space and time in collective dose assessments, although much of the collective dose associated with waste disposal might arise from very low individual doses;

- the need to take into account population exposures as a result of scenarios not included in optimization analyses;

- the need to take into account the time, location and level of individual doses when assigning a monetary value to the collective dose;

- the ICRP recommendation[2] that the social perception of the level of individual doses be taken into account in differential cost-benefit analysis by the introduction of a subjective health detriment factor;

- the uncertainties in collective dose assessments owing to the unpredictable time evolution of populations, living habits and environmental conditions.

Despite the foregoing difficulties and issues that must be resolved when establishing radiation protection criteria for disposal, the ICRP considers that disposal is within the scope of its system of dose limitation. Indeed, there is strong international pressure to apply the system in principle to ensure consistency with the current approach for reasons of inter-generational equity and since disposal practices may impact on both present and future generations. The IAEA[3] and the OECD/NEA[4] in particular have recently addressed the issues in some detail. While the basic tenets of the ICRP system of dose limitation were retained, there was recommended a different emphasis in their practical application. The ICRP itself has not yet published explicit guidance on the matter although its Committee 4 is preparing a final report[5] for approval in 1985. Not surprisingly, the general thrust of the proposed ICRP approach is expected to be similar to that developed by the NEA Expert Group.

3. IAEA CRITERIA FOR SOLID WASTE DISPOSAL

In its recommendations[3] published in 1983, the IAEA formulated in general terms five basic requirements for radiation protection that covered the operational and post-operational phases of a solid waste disposal facility. For the operational phase, the familiar principles of the ICRP, as incorporated in the IAEA Basic Safety Standards[6], were re-stated for normal operating conditions. An additional requirement for accident conditions was also given, deferring to national authorities for judging the acceptability of the radiological consequences in the manner practised in the licensing of other nuclear facilities.

For the post-operational phase, or more specifically the post-institutional control phase, the IAEA recommended that shallow land disposal facilities should meet the same radiation protection requirements as deeper facilities. These requirements were stated as follows:

- radiological detriments, as expressed by the predicted dose distributions and their probabilities of occurrence, shall be reduced to levels which are as low as is reasonably achievable, economic and social factors being taken into account;

- the radiological detriment to any individual in the future, as expressed by the predicted dose and its probability of occurrence, shall not be greater than is now regarded as acceptable for individuals.

As such, the requirements recognize that some scenarios will be very much less likely to occur than others and that the probabilities that the predicted doses will be received, as well as the magnitude of the doses, must be taken into account. This might be achieved either by directly incorporating probabilities into performance assessments and criteria or by following the traditional approach of calculating maximum individual doses and then considering their probabilities of occurrence.

With regard to the optimization requirement, the IAEA further advised that optimization was not a precise quantitative approach and that techniques such as differential cost-benefit analysis should only be used as a decision-aiding tool, bearing in mind that other factors would also influence decisions. In addressing some of the issues associated with long-term collective dose assessments, the IAEA made several suggestions. Thus, the effects of using alternative discount rates and truncation times should be examined in a sensitivity analysis. Alternatively, the use of generic dose cut-offs for limiting the calculation should be complemented by taking due account of the size of the collective dose being ignored.

4. OECD/NEA CRITERIA FOR WASTE DISPOSAL

The OECD/NEA in its report[4] on long-term radiation protection objectives for radioactive waste disposal advanced further the discussion and development of criteria. While the NEA generally endorsed the application of the ICRP philosophy to waste disposal, it emphasized the importance of protecting individuals in the long-term and further suggested that radiological acceptability be judged primarily against an individual risk limit. This risk limit would correspond to the radiological risk associated with the current ICRP recommendations on individual dose limitation, but would take directly into account the probability of exposure of a particular annual dose and the probability of a health effect arising from that dose, using a conversion factor of 10^{-2} Sv^{-1}.

For exposures of limited duration, the risk limit would be 5×10^{-5} per year, corresponding to the annual dose limit of 5mSv recommended by the ICRP for individual members of the public. For exposures of extended duration, the appropriate risk limit (or risk objective, to avoid confusion) would be 10^{-5} per year, corresponding to the annual dose limit of 1 mSv recommended by the ICRP for prolonged exposures.

Since the risk limits would apply to all sources of exposure, with the exception of medical irradiations and natural background radiation, the NEA suggested that, where appropriate, national authorities should establish risk upper bounds that are fractions of the risk limits for specific disposal practices. The NEA further noted that in the arbitrary determination of risk upper bounds, comparisons with the radiological risk from natural background radiation, or its variability in a region, have a certain appeal. Natural background radiation is relatively constant over time and provides a certain perspective on the levels of radiation exposure likely to be expected.

In applying the risk limits, the individual risks from radiation exposures associated with all scenarios must be summed, thereby taking into account probabilities and levels of exposure. These risks would be assessed for a hypothetical individual at a time and location when and where the risks are greatest, but whose metabolic characteristics are based on present knowledge. Similarly, the habits of the individual would be based on present human behaviour using pessimistic, but not unrealistic, assumptions and would be the average of a hypothetical critical group. In this way, compliance with the risk limit could be assured for an individual at any time and location.

For the unlikely situation that non-stochastic health effects would be of concern, the NEA, for the sake of completeness, recommended the assumption that doses greater or equal to 1 Sv in a year would produce such effects. While this assumption may be conservative, it translates to a limit of 10^{-5} on the probability of prolonged exposures at 1 Sv/a or greater, or of 5×10^{-5} on the probability of similar exposures of short duration.

Despite its primary concern for the protection of individuals, the NEA recommended that the optimization principle be retained for disposal practices, although it recognized that optimization techniques may not lead to a clear discrimination between alternatives when the long term is considered. The NEA nonetheless considered the various issues in conducting collective dose assessments and in assigning a monetary value to unit collective dose. It acknowledged the different views that exist but suggested that when techniques such as differential cost-benefit analysis are used these should form part of a broader, multi-attribute analysis of complete waste management strategies. Radiation protection factors that might be included in such a multi-attribute approach include:

- short-term versus long-term collective detriments;
- spatial distribution of benefits and detriments;
- distribution and levels of individual doses;
- absolute magnitudes of collective detriment and monetary cost;
- confidence in the predicted radiation exposures;

whereas non-radiological factors such as environmental impacts, socio-political impacts and other technical considerations might include:

- levels of environmental releases;
- length of institutional control requirements;
- resistance to intrusion;
- likelihood of geological disruption.

Notwithstanding the issues in applying the optimization principle, the NEA concluded that responsible decisions could still be made based on the practical application of individual risk limits and guided by appropriate consideration of other wide-ranging factors.

5. NATIONAL CRITERIA FOR WASTE DISPOSAL

Relatively few countries have issued criteria for radioactive waste disposal in either preliminary or final form. This situation reflects perhaps the specific national needs for such criteria or the desire to first achieve international consensus on the long-term issues where there are areas of agreement and where there are aspects that still ought to be resolved. As evidenced by the recent recommendations of the IAEA and the OECD/NEA, there have been significant advances in developing the international consensus. The following, however, summarizes the situation in various countries concerning disposal and the development of criteria. The information has been drawn from the literature and so care must be exercised in interpreting the meaning of the terms and language used.

5.1 Czechoslovakia

A central disposal facility in an underground limestone mine has been operated since 1964 for the disposal of wastes from the production and use of radioisotopes in industry and research. Space is limited, however, and near-surface disposal facilities are planned to accommodate the larger volume wastes from nuclear power plant operations[7].

The Czech authorities in 1977 endorsed the ICRP recommendations for individual dose limitation in the case of small population groups in the vicinity of nuclear facilities. For large population groups, the guiding value of 40 mSv/MW(e) per year for the collective dose equivalent shall not be exceeded. This figure was based on an installed capacity of 35,000 MW(e) by the year 2000. Furthermore, the contribution to individual doses from the use of nuclear energy should not exceed 0.1 mSv/a and it appears that this value applies to radioactive waste repositories.

Conservative analysis of the performance of a shallow repository at various sites showed that individual doses did not exceed 0.05 mSv/a, even for low probability scenarios. Surveillance and monitoring was proposed for 240 years.

5.2 Federal Republic of Germany

In the FRG, the disposal of all types of radioactive waste is focussed on emplacement in deep underground mines. At the Asse salt mine, pilot operations for the disposal of low and intermediate level wastes were conducted from 1967 to 1978. The mine is presently used as an underground research laboratory for waste disposal. A decision on the further use of the facility as a waste repository has been deferred until the disused Konrad iron ore mine has been licensed for construction in 1987. The Konrad mine is planned to receive non-heat generating, low and intermediate-level wastes commencing in 1989. Disposal of heat-generating, high-level waste in the Gorleben salt dome is planned to commence with the construction of the repository in 1995.

In 1983, safety criteria for the mine disposal of radioactive wastes were published[8]. The criteria advocated an overall systems approach to site-specific safety analyses and specified that mine disposal must be accomplished in a manner such that no particular control and monitoring program is necessary in the post-operational phase. More importantly, the criteria specified that in the post-operational phase, the release of radionuclides to the biosphere as a result of realistic transport processes must not lead to individual doses exceeding 0.3 mSv/a, the value given in Article 45 of the German Radiation Protection Regulations. There was no requirement for optimization using collective dose assessments. The criteria further specified that safety analyses of the total system, including the effects of disruptive events, must be conducted using models based on conservative assumptions.

5.3 Finland

In Finland, reactor operating and decommissioning wastes are planned to be disposed of in intermediate depth mines in the bedrock of nuclear power plant sites with commencement of disposal activities by the end of 1992. For spent fuel disposal, Finland advocates the use of an international repository but in the event this goal is not achieved, a domestic site in Precambrian bedrock must be selected by the end of the year 2000.

Although no criteria for disposal have been established, safety analyses of both types of repository indicate that annual individual doses are less than 0.02 mSv in the post-closure phase. This compares with the Finnish limit of 0.1 mSv/a for individual doses to members of the public from the operation of nuclear power plants.

5.4 France

In France, the Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA) operates a shallow land disposal facility at Centre de la Manche for low and intermediate-level β, γ waste. This site is expected to be full in several years time and two new shallow land disposal sites are to be selected in 1985. For significant amounts of long-lived, low and intermediate-level wastes, principally α-wastes from spent fuel reprocessing, a geological disposal facility is planned to be built commencing in 1992. For vitrified high-level wastes, a candidate deep geological disposal site is to be selected in 1987 followed by the construction of an underground site validation facility commencing in 1988.

Safety rules and criteria for the disposal of long-lived α-waste and of vitrified high-level waste have not yet been issued. For shallow land repositories, a new safety rule[9] was published in 1984. This rule specifies inter alia that the total activity must be limited so that the surveillance period does not exceed 300 years and that thereafter, during the unrestricted access period, the radiological risks should be negligible for any type of human activities. This will be achieved by limiting the concentration of long-lived α-emitters in the β, γ -waste originally being emplaced.

Based on an individual dose of 1 mSv/a and construction and residential intrusion scenarios, an average α-concentration of 370 Bq/g for the site was derived. The probability of intrusion was assumed to be unity and no

assessments of collective dose were made. Limits on the total activity to be disposed of would be based on a site-specific analysis.

5.5 Sweden

In Sweden, low and intermediate-level reactor operating and decommissioning wastes are to be disposed of in an intermediate-depth mined repository in the bedrock near the Forsmark nuclear power plant site but below the sea bed. This repository is presently under construction and is scheduled to be commissioned in 1987. As a pre-requisite to fuelling new reactors, the Swedish government in 1984 accepted the KBS-3 safety analysis report on the concept of disposing of spent fuel about 500m deep in bedrock. The availability of a deep geological repository for nuclear fuel waste is planned for 2020.

In assessing the application to construct the repository for reactor waste, the National Institute of Radiation Protection used the following criteria:

for the post-closure phase until the next ice age (assumed to be 10,000 years from now)

- all doses to individuals now and in the future shall be given the same weighting and shall not exceed the limiting values currently used for planning purposes for other parts of the nuclear fuel cycle (the most important of these being a dose limit of 0.1 mSv/a);
- the build-up of radioactive substances in the biosphere, caused by release in the distant future must be taken into account;
- higher doses to individuals can be accepted for extreme and improbable occurrences provided that the doses do not become so large that acute radiation injuries may occur (assumed at 1 Sv);
- the collective dose from handling and storing the waste shall not appreciably change the dose picture for the whole nuclear fuel cycle;

for the period beyond the next ice age

- no account will be taken of events that might occur.

In assessing the KBS-3 report, the Institute also considered the individual-related criteria to be relevant for the period until the next ice age[10]. However, it rejected the collective dose criterion on the grounds of the large uncertainties involved in the calculation of future collective doses and of the study being a generic assessment of a reference concept.

For the period beyond the next ice age, the Institute contended that no basis exists for the calculation of radiation doses, although doses could be used as a measure of what future releases would have meant if the releases had occurred to the present-day biosphere. On the other hand, the Institute considered that an acceptability criterion should be based on radionuclide releases to the biosphere being no more than a small fraction of the natural inflow of naturally occurring radionuclides to the biosphere due to processes such as weathering. The Institute is developing criteria along this line for the first post-glaciation period and considers that an additional contribution to the

natural inflow of the order of 1% would not make any appreciable difference to biological evolution.

5.6 Switzerland

In Switzerland, domestic solutions for the disposal of all types of radioactive waste are being planned in the event that international projects do not materialize. Thus, three sites have been selected in different geologic formations for detailed site characterization studies leading to the development of an intermediate-depth repository for low and intermediate-level wastes by 1995. For high-level wastes, current studies are focussed primarily on deep disposal in crystalline bedrock, although other host formations have not been excluded. An underground rock laboratory in granite, accessed horizontally from an existing tunnel system near Grimsel, was opened in 1984 to provide a test-bed for methodology to be applied later at potential sites for both intermediate-level and high-level wastes.

In the meantime, there is a requirement to demonstrate to the Swiss government in 1985 that the safe disposal of all types of radioactive wastes is feasible in principle. Regulatory criteria were published in 1980 in the form of protection goals that define the performance of the overall disposal system[11]. These goals set the standards for waste disposal and relevant ones are stated as follows:

- radionuclides which, subsequent to realistic processes and events, return from a sealed repository to the biosphere must at no time give rise to individual dose equivalents exceeding 0.1 mSv/a;

- if the effects of several repositories overlap, the dose limit applies to the sum of all contributions;

- after the sealing of a repository it must be possible to abandon all safety and surveillance measures.

In applying the first protection goal, the rejection of events considered to be unrealistic must be supported by convincing arguments, such as extreme improbability or the radiological consequences being small compared to the non-radiological consequences. While there is a qualitative requirement to reduce the radiological risk due to a repository to as low as reasonably achievable, there is neither a requirement to estimate collective dose nor a requirement to conduct a differential cost-benefit analysis. Compliance with the protection goals is intended to be demonstrated using deterministic modelling of specific scenarios. Conservative assumptions will be used to help deal with uncertainties and incompleteness in the models and data.

5.7 United Kingdom

In the UK, the government has decided that the safety and feasibility of deep geologic disposal of high-level waste have been established in principle. It has further decided that the disposal of vitrified high-level waste be deferred in favour of interim storage for at least 50 years. For low and intermediate-level wastes the situation is different. British Nuclear Fuel plc has operated for many years a shallow land disposal facility for low-level wastes near its Sellafield site, but there is a need to establish new land-based facilities for

for both low and intermediate-level wastes.

Engineered shallow land burial designs are being studied for short-lived, low and intermediate-level wastes and for which institutional controls would not be required beyond, at most, 300 years. Deeper mined facilities are being studied to accommodate significant quantities of long-lived waste, principally from fuel reprocessing operations. Recent developments have, however, resulted in requirements to conduct detailed investigations of at least three sites for any type of new disposal facility. The shallow, clay site at Elstow has been retained for further consideration but the disused anhydrite mine at Billingham has been dropped from further consideration in view of a planned review of waste conditioning options.

Also announced in 1985 were the final criteria to be applied by the authorizing Departments to the land-based disposal of low and intermediate-level wastes[12]. For the post-institutional management period, the authorizing Departments took into account the advice and recommendations of the UK-NRPB[13], the IAEA[3] and the OECD/NEA[4] in formulating criteria based on risk to the individual. Thus, the authorizing Departments will be guided by the following objective:

- the risk to any member of the public in any one year, from exposure to radiation from all sources other than background and medical exposure, should not be greater than that associated with a dose of 1 mSv. (In the UK, the assumed annual risk of death from radiation exposure of 1 mSv/a is 1 in 100,000).

In order to take account of exposure pathways and health effects not at present recognized, and avoid prejudicing any future decisions that might lead to other activities which cause radiation exposure to the same members of the public, an additional margin of safety would be required. The appropriate target applicable to a single repository at any time was therefore established as a risk to an individual in a year equivalent to that associated with a dose of 0.1 mSv; that is, about 1 chance in a million.

With respect to optimization, the authorizing Departments stated that during the operation of a facility, and thereafter, the need to ensure that exposures from radiation are as low as reasonably achievable, taking into account economic and social factors, will be applied and may well bring doses down to below the target levels. This would be achieved by requiring operators to use the best practicable means to ensure that any radioactivity released from a facility is as low as reasonably practicable.

5.8 United States of America

In the USA, radioactive wastes are generated at all steps in the nuclear fuel cycle from uranium mining and milling to reactor operations and from the use of radioisotopes in industry, research and hospitals. Separate programs, approaches, regulations and criteria have been, or are being, developed for the management and disposal of three major waste groups — uranium mill tailings, low-level reactor operating and radioisotope wastes and high-level radioactive wastes. In general, the Environmental Protection Agency is responsible for establishing environmental radiation protection standards upon which the Nuclear Regulatory Commission bases its detailed regulations for licensing

various activities.

5.8.1 Uranium Tailings

For perhaps obvious reasons, large-volume uranium mill tailings are managed close to mine and mill sites. In 1983, the EPA announced final criteria in 40 CFR Part 192 applicable to inactive uranium processing sites[14]. For the control of residual radioactive materials the following criteria were specified:

- control shall be designed to:

  (a) be effective for up to 1000 years, to the extent reasonably achievable, and, in any case, for at least 200 years, and

  (b) provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not:

  (i) exceed an average release rate of 20 $pCi/m^2/s$, or

  (ii) increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than 0.5 pCi/l.

For the clean-up of contaminated lands and buildings, the following criteria were specified:

- remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

  (a) the concentration of radium-226 in land averaged over any area of 100 m^2 shall not exceed the background level by more than:

  (i) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and

  (ii) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface;

  (b) in any occupied or habitable building:

  (i) the objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL; in any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and

  (ii) the level of gamma radiation shall not exceed the background level by more than 20 $\mu R/hr$.

In establishing the above criteria, the EPA adopted the objectives of:

- taking into account the trade-offs between costs and benefits in a way that would assure adequate protection of public health and safety and the environment;

- implementing the criteria using presently available techniques and measuring instruments;

- reasonableness in terms of overall costs and benefits.

The EPA stated that these criteria would not necessarily be applicable to active or future uranium mill sites for which standards are under development.

5.8.2 Low-Level Wastes

For low-level wastes, three commercially-operated shallow land disposal facilities are presently operated in the States of Washington, Nevada and South Carolina. However, the Low-Level Radioactive Waste Policy Act of 1980 made each State responsible for assuring adequate disposal for low-level waste generated within its borders, but allowed States that agreed to a regional compact the authority to exclude low-level waste from outside their region, beginning in 1986. This has stimulated the search for new solutions to low-level waste disposal.

An advanced notice of proposed rulemaking was issued in 1983 by the EPA concerning low-level waste disposal. Prior to this announcement, the NRC issued final criteria in 10 CFR Part 61 for low-level waste disposal in shallow land facilities[15] and the relevant criteria were as follows:

- protection of the general population from releases of radioactivity: concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 mrem to the whole body, 75 mrem to the thyroid, and 25 mrem to any other organ of any member of the public; reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable;

- protection of individuals from inadvertent intrusion: design, operation and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed.

The first criterion was based on the EPA standards for the uranium fuel cycle[16] issued in 40 CFR Part 190 in 1979. The second criterion was based on an annual dose of 500 mrem to the whole body and a limiting institutional control period of 100 years after the transfer of responsibility from the site operator to the site owner. Using these criteria, generic concentration limits were derived for specific radionuclides and classes of low-level wastes.

5.8.3 High-Level Wastes

The Department of Energy is responsible for implementing the disposal of high-level wastes and under the Nuclear Waste Policy Act of 1982 is required to

develop the first deep geological repository to begin receiving high-level waste in 1998. Three sites in basalt, volcanic tuff and bedded salt have recently been proposed by the DOE for detailed site characterization studies. In 1982, the EPA proposed criteria in 40 CFR Part 191 for the management and disposal of spent nuclear fuel, high-level and transuranic radioactive wastes[17]. For the active management period, the proposed criteria were generally in accordance with 40 CFR Part 190. For the post-closure period, the following criteria in particular were proposed:

- containment requirements:
  disposal systems for high-level or transuranic wastes shall be designed to provide a reasonable expectation that for 10,000 years after disposal:

  (a) reasonably foreseeable releases of waste to the accessible environment are projected to be less than certain radionuclide-specific cumulative release limits;

  (b) very unlikely releases of waste to the accessible environment are projected to be less than 10 times the limits for reasonably foreseeable releases;

- assurance requirements:
  to provide the confidence needed for compliance with the containment requirements:

  (a) disposal systems shall be selected and designed to keep releases to the accessible environment as small as reasonably achievable, taking into account technical, social and economic considerations;

  (b) disposal systems shall not rely upon active institutional controls to isolate the wastes beyond a reasonable period of time (e.g. a few hundred years) after disposal of the wastes;

- procedural requirements:
  performance assessments to determine compliance with the containment requirements shall:

  (a) consider realistic projections of the protection provided by all of the engineered and natural barriers of a disposal system;

  (b) not assume that active institutional controls can prevent or reduce releases to the accessible environment beyond a reasonable period (e.g. a few hundred years) after disposal;

  (c) use information regarding the likelihood of human intrusion, and all other unplanned events that may cause releases to the accessible environment, as determined by the implementing agency for each particular disposal site.

In the above criteria, "accessible environment" includes the atmosphere, land surfaces, surface waters, oceans, and parts of the lithosphere that are more than 10 km in any direction from the original location of any of the

radioactive wastes in a disposal system. "Reasonably foreseeable releases" means releases of wastes to the accessible environment that are estimated to have more than 1 chance in 100 of occurring within 10,000 years. "Very unlikely releases" are releases having between 1 chance in 100 and 1 chance in 10,000 of occurring within 10,000 years.

Although neither individual dose limits nor collective doses were mentioned in the post-closure criteria, cumulative radionuclide releases at the specified limits from the wastes generated from 100,000 metric tons of heavy metal were estimated to cause no more than 1,000 premature cancer deaths in the first 10,000 years after disposal; that is, an average of no more than one premature cancer death every 10 years. This was compared with the approximately 4,000 premature cancer deaths per year in the US population that may be calculated from exposure to natural background radiation. The EPA also compared this figure with the 300 to more than 1,000,000 excess cancer deaths over 10,000 years estimated from exposures associated with releases from the equivalent amount of unmined uranium ore.

The proposed EPA criteria were subsequently incorporated in the final regulations for geologic disposal of high-level wastes[18] issued as 10 CFR Part 60 by the NRC in 1983. In these regulations, the NRC established numerical performance criteria for the engineered barrier system and for the geologic setting which would contribute to assuring that the EPA criteria for overall system performance would be met.

6. CRITERIA FOR WASTE DISPOSAL IN CANADA

As in the USA, a wide variety of radioactive wastes are generated in Canada. Federal programs have also been established to address the management and disposal of the three major types of waste - uranium mill tailings, low-level wastes and nuclear fuel wastes - although the programs, schedules, jurisdictional responsibilities and regulatory approaches differ in detail from those in the USA.

6.1 Uranium Tailings

There are upwards of 130,000,000 tonnes of uranium tailings located in various surface impoundments near mine and mill sites in Ontario and Saskatchewan. At active sites the management of tailings is regulated on a site-specific basis by the Atomic Energy Control Board in conjunction with the appropriate provincial authorities. In an effort to address criteria for the long-term aspects of uranium tailings management such that requirements and guidelines could be developed for the decommissioning of active tailings facilities, the AECB issued Consultative Document C-1 in 1981[19]. This document contained performance-oriented criteria for releases and gamma levels of the type later promulgated by the EPA in 40 CFR Part 192. The current draft of the document[20] explicitly references the requirements for individual dose limitation and optimization rather than numerical performance-oriented criteria. It also takes into account the experience gained in authorizing the site-specific decommissioning of three tailings operations.

Supporting studies for the development of criteria for the long-term aspects of uranium tailings are primarily being funded through the National Uranium Tailings Program. This program is in the third year of its five-year term

designed to address the three areas of measurements, modelling and technology development, with the main thrust being the development of appropriate long-term modelling methodologies.

6.2 Low-Level Wastes

Federal programs for low-level waste disposal are active in four main areas. The federal Low-Level Radioactive Waste Management Office is in the process of finding solutions for the clean-up of sites contaminated with historic wastes for which the waste generator can no longer be held responsible. The Office is also developing a national strategy for the disposal of on-going low-level waste arisings. At the same time, Atomic Energy of Canada Limited and Eldorado Resources Limited are developing disposal concepts for their low-level wastes presently at Chalk River Nuclear Laboratories and near Port Hope, respectively. These concepts include shallow land burial in unconsolidated sediments and deeper burial in bedrock. No criteria specific to low-level waste disposal have yet been proposed by the AECB. However, of relevance in this regard are the final regulatory policy statement on nuclear fuel waste disposal[21] and a proposed regulatory policy statement to be issued imminently on the disposal of very low-level wastes in a manner exempt from AECB licensing[22].

6.3 Nuclear Fuel Wastes

The concept assessment phase of the Canada-Ontario Nuclear Fuel Waste Management Program is scheduled to conclude by the end of 1990 with a government statement on the acceptability, in principle, of the concept of deep geologic disposal of nuclear fuel waste in crystalline rock. Prior to this, a public hearing will be held on all aspects of the concept and the AECB will make its statement concerning concept acceptability.

In 1982, the AECB issued a proposed regulatory policy statement on the regulatory review and assessment of the disposal concept. This statement was revised and finalised taking into account the comments received from the nuclear industry, government agencies and the general public and was re-issued as Regulatory Document R-71 in January, 1985[21]. For the post-closure period, the following criteria in particular were specified:

- the performance of the waste repository must be such that the probability of radiation doses to members of the public, attributable to the existence of the repository, exceeding a small fraction of the doses received from natural background radiation, must be small;

- the waste repository must be designed in such a way that no dependence on intervention or maintenance by future generations is necessary to ensure continued safety;

- a disposal system must be able to accommodate natural disturbances likely to occur, such that any increase in risk to members of the public as a result of these disturbances will be insignificant.

For the performance assessment, requirements were specified for calculations of annual individual effective dose equivalents as a result of possible releases of radionuclides, for consideration of inadvertent human intrusion, for justifying the choice of boundary conditions and for estimating the

uncertainties in the data or analysis. There were no requirements for calculating collective dose or for optimization in the concept assessment phase.

7. CONCLUSIONS

From national and international discussions it is clear that there are difficulties in applying, in a practical sense, the ICRP system of dose limitation to the post-closure or post-institutional control period of radioactive waste disposal systems. There are specific difficulties in particular when considering the use of formal quantitative techniques, such as differential cost-benefit analysis, for satisfying the optimization principle. These may become of minor importance, though, when other non-radiological factors are taken into account in decision-making.

Although significant advances have only recently been made in the international arena to reach consensus on a more practical and alternative approach to setting criteria, a number of countries have establish national criteria with which to guide and judge domestic programs. These criteria are primarily stated in terms of protection of individuals at levels that correspond to a small fraction of the individual dose limits recommended by the ICRP for present-day operations. In the USA in particular the situation is more complex with different types of criteria being promulgated for the different major waste types. The criteria are nonetheless related to levels of radiation exposure that are considered acceptable.

There is also clear recognition by most countries that the individual-related criteria apply to likely or more realistic exposure scenarios and that for less likely scenarios, higher radiation doses would be acceptable. In this respect, the UK in particular has formally adopted criteria in terms of individual risk in a manner that accounts for the probability of the exposure scenario and the probability of a health effect as a result of exposure.

For the geologic disposal of wastes, some countries including Canada have made reference to, or propose to consider some aspect of, natural background radiation or its components in specifying a performance criterion. The USA and Sweden have both identified 10,000 years as being the time for which primary criteria apply for geologic disposal and for which performance assessments must demonstrate compliance.

For the near-surface disposal of wastes, including the management of uranium tailings, the role of institutional controls and the potential accessibility by humans are important in determining primary criteria, derived criteria and the time for which performance assessments must be conducted. Explicit indications of the latter only appear in the US rules and regulations.

Finally, there is also a clear indication that requirements for formal quantitative techniques for optimizing radiation protection have not been incorporated in national criteria for waste disposal. The need for optimization has nonetheless been generally endorsed but in perhaps a rather qualitative way, bearing in mind that decisions will ultimately be made in a broader multi-attribute framework.

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